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INTERPRETATION OF K-Ar AND Rb-Sr ISOTOPIC DATES FROM A PRECAMBRIAN BASEMENT CORE, ERIE COUNTY, PENNSYLVANIA

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PREFACE

Appalachian geologists have few opportunities to study rocks as old as the Precambrian and even less opportunity to get data west of the Piedmont where such rocks are deeply buried beneath more than a mile of sedimentary rock cover. A well drilled near Lake Erie in Pennsylvania penetrated Precambrian rocks at a depth of 5952 feet and provided an excellent opportunity to describe in detail these rock types that up to now have been inaccessible. Included are petrographic descriptions, radiometric age dates, and a description of the complex events which, at least locally, have affected the rocks.

The oldest rock, now a gneiss, is a least 1100 million years old and perhaps older. It is believed to have been an extrusive lava flow originally which subsequently was metamorphosed, intruded by granite and pegmatite, and invaded by sericite. The youngest recorded alteration occurred 530 to 560 million years ago and is believed to have been a chemical leaching.

The results of this study are significant. Precambrian rocks now definitely have been identified from beneath the plateau of northwestern Pennsylvania; their exact depth is known; and the rocks here can be compared with similar subsurface samples from Ohio, with samples of exposed Precambrian rocks to the east throughout the northern Appalachians, and with the rocks of the Canadian Grenville Province, and events and processes that affected these rocks can be placed within a regional framework for a better understanding of the geologic history of the area.

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INTERPRETATION OF K-Ar AND Rb-Sr ISOTOPIC DATES FROM A PRECAMBRIAN BASEMENT CORE, ERIE COUNTY, PENNSYLVANIA

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ABSTRACT

A core drilled near Lake Erie, Pennsylvania, penetrated strongly foliated, quartz-biotite gneiss intruded by weakly foliated, microcline granite at a depth of 5952 feet. Both fabrics are transected and the granite partially replaced by sericite. The gneiss contains relict phenocrysts, possibly from an extrusive and evidences no retrograde metamorphism. Above 5972 feet and below 5952 feet, granitic injections formed a lit-par-lit striped gneiss. Thin shale, dolomite, and massive sandstone believed to be Cambrian lie above 5952 feet. A 908 million year K/A age on the gneiss contrasts strongly with gneiss and granite Rb/Sr ages of about 530 or 560 million years ($\lambda Rb^{87} = 1.47 \times 10^{-11} yr^{-1}$ and $1.39 \times 10^{-11} yr^{-1}$, respectively), assuming a valid two-point isochron for which the Sr^{87}/Sr^{86} intercept is 0.710.

Interpretation of the large apparent age discrepancy for K/Ar and Rb/Sr radiometric systems is limited by problems involving 1) inherited argon, assumed to be negligible, 2) the validity of a two-point isochron, 3) a possible radiogenic-strontium leaching process of nearly equivalent magnitude in granite and gneiss which had little effect on argon loss in biotite gneiss, and 4) an assumed re-equilibration of the K/Ar system in gneiss by granite injection and probably by sericitization.

A presumed 1100 million year regional metamorphism to biotite gneiss was followed by a granite with late pegmatitic development and finally sericitization that caused closure of the K/Ar system at about 908 million years. Subsequently, by a process not petrographically observable, radiogenic strontium may have migrated from granite and gneiss, yielding approximate closure of the Rb/Sr system at 530 to 560 million years, possibly correlative with episodic, lowermost Paleozoic events to the east.

INTRODUCTION

The Hammermill No. 2 well from near Lake Erie, Erie County, Pennsylvania (Figures 1 and 2 of Saylor, 1968) reached a depth of 5972 feet. The well was cored (3.5 inch diameter) and logged. Above 5952 feet (5290 feet below sea level) thin shale and silty dolomite are overlain by massive sandstone and underlain by schistose biotite gneiss. This contact was taken to be the Cambrian-Precambrian boundary based on 1) a lithologic correlation of the cored sandstone with typical lower Cambrian sandstone, 2) a lithologic correlation of cored gneiss with typical Precambrian basement rock, and 3) agreement with contours for the top of the Precambrian basement (Saylor, 1968, Figure 2).

A sample consisting of schistose biotite gneiss in vertical contact with slightly foliated granitic lithology from 5972 feet was studied petrographically by Saylor (1968). Schistosity in the gneiss is essentially vertical and parallel to the granite contact. A modal analysis of the granite revealed the following major constituents in order of decreasing abundance: quartz, muscovite (coarse and fine grained), biotite, potassic feldspar, and plagioclase (Saylor, 1968, p. 7). Modal analysis of biotite gneiss revealed the following constituents in order of decreasing abundance: biotite, quartz, fine-grained muscovite (sericite), very minor plagioclase, and potassic feldspar (Saylor, 1968, p. 8). Pegmatitic veins at the granite-gneiss contact at 5972 feet are composed largely of quartz with minor coarse-grained muscovite. Several porphyritic grain aggregates, now largely composed of isotropic material and replacement sericite, were noted in the biotite gneiss (Saylor, 1968, p. 8) and may be relict pyroxene (or olivine?). From this sample at 5972 feet a schistose portion of biotite gneiss was selected for K/Ar and Rb/Sr isotopic analysis and a sample of the foliated granite one inch from the contact was selected for Rb/Sr analysis (insufficient material was available to perform a K/Ar analysis).

Since the work of Saylor (1968), additional core material between 5972 feet and 5952 feet has been made available for study. To supplement his geologic description and to assist in interpreting the isotopic age data, additional macroscopic, petrographic, and X-ray studies have been carried out. A more complicated series of geologic events now has been recognized in the Erie County basement rocks and these observations are pertinent to interpretation of the apparent radiogenic ages.

ACKNOWLEDGMENTS

Core samples and a lithic log of the core was kindly supplied by W. R. Wagner, Pennsylvania Geological Survey. The author is particularly grateful to Arthur A. Socolow, State Geologist of Pennsylvania, for support

for the radiometric analyses and for his encouraging interest in the interpretive aspects of the project and to David MacLachlan and Edward Lidiak for their helpful criticism of this manuscript.

REGIONAL GEOLOGIC SETTING

Precambrian lithologies from eastern Ohio and from western Pennsylvania southeastward belong to the subsurface extension of the Canadian Grenville belt, largely composed of metamorphic rocks. The most abundant subsurface lithologies are granitic, often banded biotite gneiss or weakly foliated granite, with minor basalt, amphibolite, dolomitic marble, quartzite (possibly Cambrian) and syenite, all of greenschist or amphibolite facies (Bass, 1957 and 1960; Summerson, 1962; Rudman and others, 1965; Muehlberger and others, 1967; Saylor, 1968). Saylor (1968) has pointed out that the granitic Precambrian rocks range from granodioritic to tonalitic in West Virginia with amphibolite decreasing southward from Pennsylvania.

Grenville orogenic metamorphism is generally believed to have occurred about 1100 million years ago (Lidiak and others, 1966). Radiometric ages on Grenville belt Precambrian samples range from about 300 million years (K/Ar) for samples re-equilibrated in Paleozoic time (see Summary in Lapham and Root, 1971) to about 1100 million years; a few are reported as old as 1300 million years (Rudman and others, 1965, Figure 8; Goldich and others, 1966). Ages younger than about 800 million years are common for Piedmont samples of Precambrian lithologies (Tilton and others, 1960; Wetherill and others, 1966; Lapham and Root, 1971) but have not been previously recorded for the subsurface Precambrian of Ohio, Pennsylvania, and West Virginia. Post-Grenville igneous activity, tectonism, and thermal re-equilibration in Pennsylvania appear to have been episodic and somewhat restricted to particular geologic provinces (Lapham and Root, 1971). Apparent-age maxima at which equilibration might have occurred fall into the following groups: 800-900 million years, 550-650 million years (Neponset and Avalonian orogenies), 420-480 million years (culminating in the Taconic orogeny), 310-350 million years (Acadian events), and a few between 240 and 260 million years (Lapham and Root, 1971).

West of the buried Grenville province the maximum age increases to about 1200-1500 million years and the dominant lithologies are granite and rhyolite with minor trachyte and basalt (Lidiak and others, 1966). The age and lithologic boundary has been considered as the subsurface extension of the Grenville front through central Ohio (Bass, 1960; Muehlberger and other, 1967) or through central Indiana (Rudman and others, 1965).

GEOLOGIC DESCRIPTION AND PROCESSES

INTRODUCTION

In terms of texture (Figures 1 and 2), mineralogy (Tables 1 and 2), and processes, the core samples studied from the Hammermill No. 2 well in Erie County are more complex than the single sample studied by Saylor (1968) indicated. Because of this complexity, the descriptions here may not be representative of the subsurface Precambrian basement in northwestern Pennsylvania, although grossly similar lithologies have been described by Saylor (1968) from this region. There are two general lithologies, a strongly foliated, commonly schistose biotite gneiss that is the dominant lithology, and a weakly foliated leucocratic granitic rock. These lithologies henceforth will be referred to as "biotite gneiss" and "granite".

THE BIOTITE GNEISS

The biotite gneiss is texturally and compositionally a hybrid rock. The dated sample from the base of the core at 5972 feet (Figures 1-A and 2-A) is a strongly foliated, irregularly and discontinuously banded, porphyritic or relict phenocrystic (Figure 3), and porphyroblastic biotite schist. The foliated melanocratic bands are composed principally of coarse-grained (up to 3.0 millimeters) biotite with minor quartz (15-25%). Mesocratic bands, composed principally of fine-grained (0.1 millimeter) sericite (largely 1Md muscovite) with a trace of cloudy, untwinned orthoclase (0-3%), commonly are parallel to the biotite foliation, but also transect it. These mesocratic bands constitute 10-40 percent of the sample. Microcline was observed only near the granite contact and occurs with sericite, transecting the biotite-quartz laminae (Figure 2-A). Biotite is not altered and chlorite is absent (Table 1). Quartz grains are elongate parallel to the foliation, subhedral to euhedral, interlocking, and generally not strained. Quartz occurs principally along the margins of biotite laminae, between biotite and sericite bands, or, where sericite is absent, separating biotite laminae (Figures 2-A and 2-D). Shredded muscovite flakes (0-2%) occur sparingly, surrounded and replaced by biotite.

Large (2-4 millimeter), altered, relict phenocrysts (about one percent of the rock) now are largely isotropic with an altered matrix, crude mesh texture, and are surrounded or invaded by sericite and quartz (Figure 3). Biotite foliation wraps around the phenocrystic aggregates. Two types have been observed: 1) colorless, isotropic, shard-like areas replaced by sericite and separated by muscovite shreds (Figure 3) and, 2) green, isotropic areas (finer-grained muscovite than type 1), opaque-oxide dust, and with an apparently relict mesh texture. Type 1 may have been a

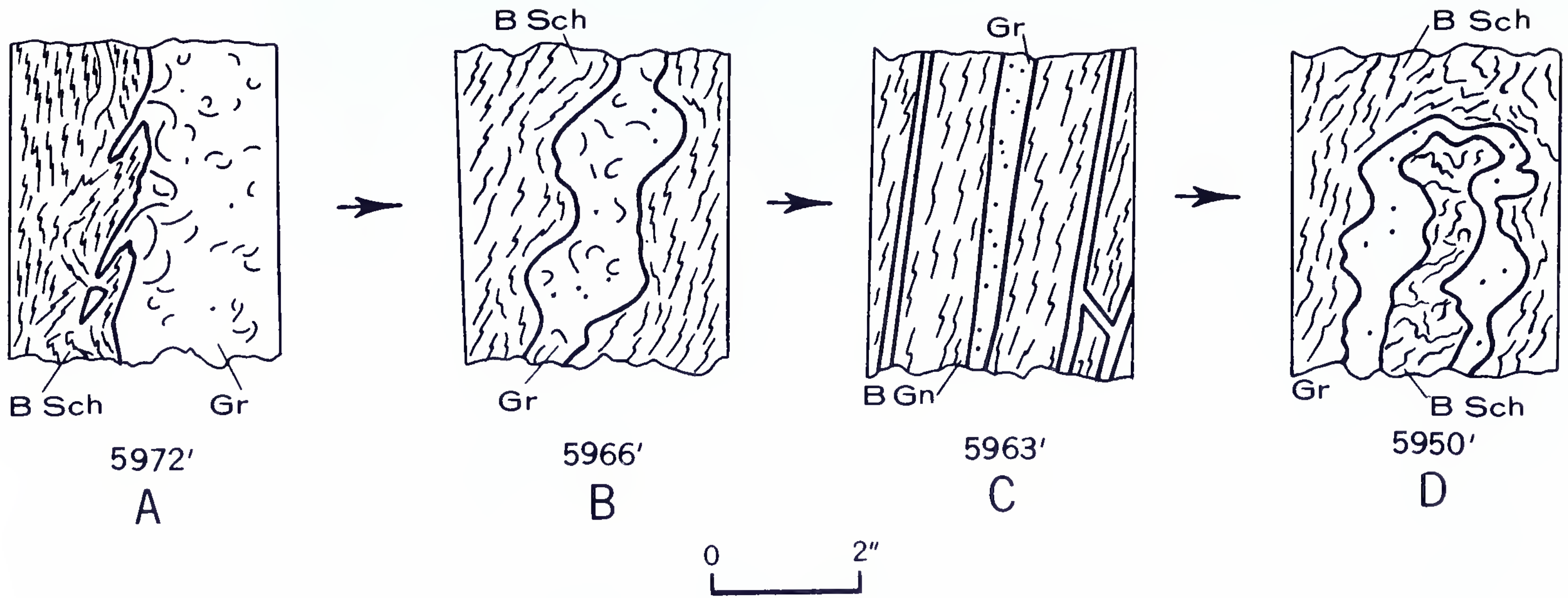

Figure 1. Gross textures of the Hammermill No. 2 core from 5972 feet to 5950 feet illustrating granitic invasion (A) and upward injection into biotite gneiss (B-D); B = biotite, Gn = gneiss, Gr = granitic material, Sch = schist.

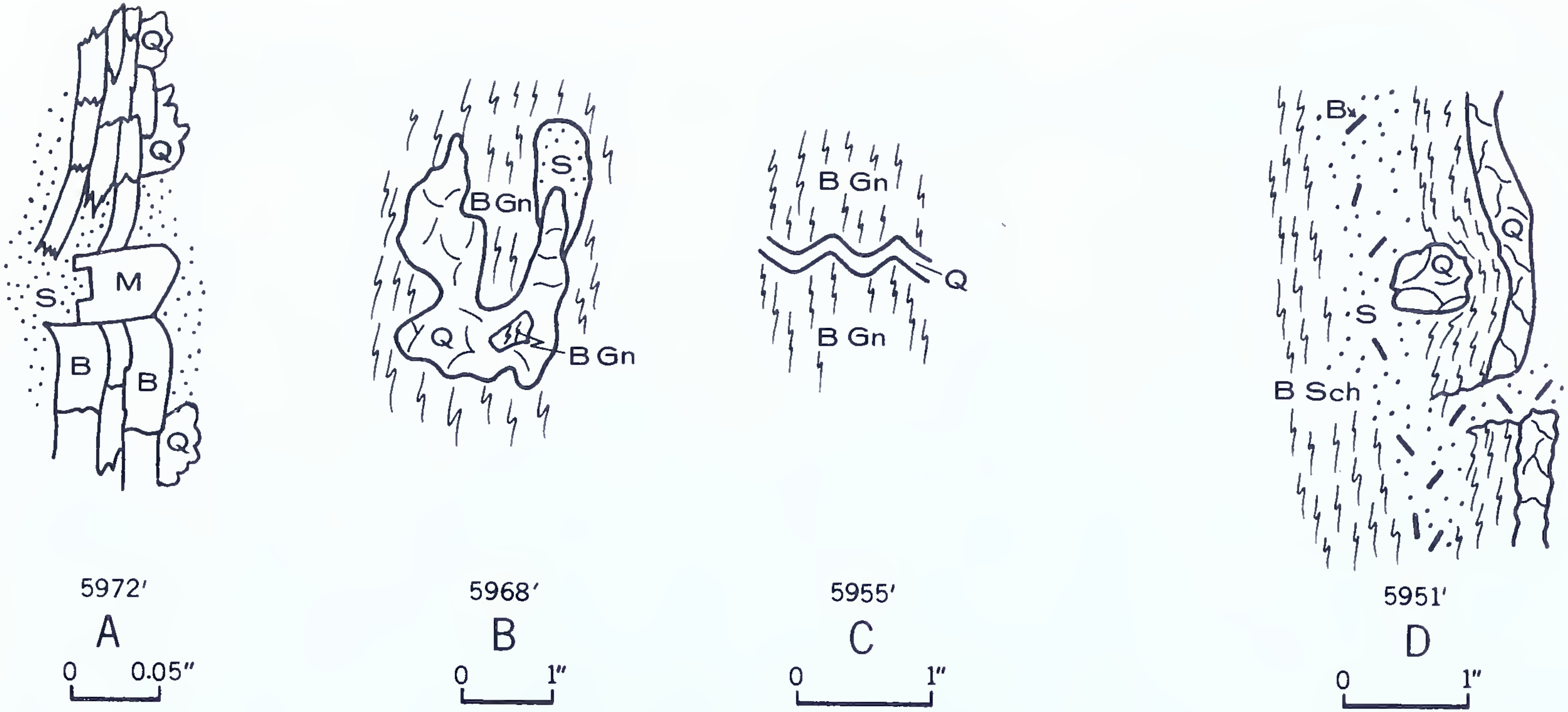

Figure 2. Textural details of biotite gneiss from the Hammermill No. 2 core illustrating relationships of sericite and granitic injection to biotite gneiss; B = biotite, Gn = gneiss, M = microcline, Q = quartz, S = sericitic muscovite, Sch = schist.

pyroxene or feldspar and type 2 closely resembles altered olivine, although serpentine is not present. The isotropic areas in both are rimmed by magnetite (Figure 3). Size ranges between 2.0 and 3.0 centimeters, although some have been disrupted subparallel to the foliation plane.

Above 5972 feet, textures range from biotite schist with granitic pods or veins (Figures 1-B, 1-D and 2) to a discretely banded, striped biotite gneiss (Figure 1-C), both with relict phenocrysts. Areas of biotite schist enclosed by granitic material not uncommonly are somewhat coarser grained (Figure 1-D). The leucocratic bands and schlieren generally parallel the foliation, but occasionally transect it (Figures 1-D and 2). A few samples exhibit no conspicuous banding at the scale of observation (Figure 1-A, left side). The finer-grained portions are spotted, biotite schists, the leucocratic spots being either sericite (most common), quartz (less common; Figure 2-D), or potassic feldspar (least common; Figure 2-A). Thus, sericite occurs in biotite gneiss throughout the vertical core (Figure 2) but locally is quite variable in distribution.

Figure 3. Photomicrograph of relict phenocryst contact (center and left) with biotite gneiss (right) illustrating invasion by sericite (mottled dark gray) and ellipsoidal areas of isotropic material; plane polarized light; X5.

Table 1. *Mineral Compositions of Biotite Gneiss (in %)*

	HM2-BP Isotopically Dated Schistose Quartz-Biotite Gneiss	*Compositional Range of Quartz-Biotite Gneiss*
Quartz	34	20-60
2M Muscovite	<1	0-1
1Md Muscovite	15	5-25
Biotite	46	25-85
Microcline	$\ll 1$	$\ll 1$
Orthoclase†	<1	0-1
Plagioclase	2	0-2
Apatite	$\ll 1$	0-1
Magnetite	<1	0-1
Isotropic*	~ 1	$\sim$ 1-4

† Untwinned potassic feldspar, at least in part microcline
* Isotropic relict phenocrysts; sericitized

Because of the textural differences and lack of uniform distribution of lithologies, the mineral composition of the biotite gneiss throughout the core is variable (Table 1). The general compositional range of biotite gneiss and schist where it is not adjacent to granite (i.e., above the 5972′ sample) is given in Table 1. The most abundant minerals are biotite and quartz, with biotite predominating where the scale of observation is two inches or more. Except for replacement sericite, all other minerals are in minor to trace amounts throughout the core and the general mineralogy corresponds to that at 5972 feet. Differences largely are in the upward-increasing abundance of the leucocratic material, predominantly quartz with minor microcline and sparse, well-crystallized 2M muscovite up to 2.0 millimeters in diameter. Some of these laminae are composed entirely of interlocking, subhedral to anhedral quartz grains (e.g. in Figure 2-D). Quartz aggregates also occur (Figure 2-D). The contact between biotite schist or gneiss bands and leucocratic laminae is sharp (Figure 1); in contrast, the contact with mesocratic sericitic areas is gradational (Figures 2-A and 2-D).

Mineral paragenesis in biotite gneiss could be determined only crudely, and falls into three major groups. The earliest minerals to form were the phenocrysts now altered to isotropic aggregrates and the shredded muscovite flakes enclosed by biotite, both in the melanocratic laminae. The two micas are suggestive of polymetamorphism, but good evidence is lacking. The second group contains the two principal minerals, biotite and quartz, some quartz perhaps being the older (Figure 2-D) and some younger (Figure 2-C). The youngest group of minerals includes sericite and microcline (Figures 2-A and 2-D). Deformation occurred previous

to the formation of the granitic material that both invades the biotite gneiss and disrupts its foliation (Figure 1-A). Slip deformation also occurred after or during the formation of cross-cutting vein quartz (Figure 2-C), but previous to sericitization.

The banded, porphyritic and porphyroblastic biotite gneiss clearly is a metamorphic rock now largely in the biotite isograd of the greenschist facies, but possibly with some higher grade minerals (Table 1). A lower, retrograde facies characterized by chlorite or zeolites has not been recognized. The original character of the rock is largely obscured, both by metmorphism and by replacement. The presence of large, nearly spherical phenocryst relicts, now fractured, and isotropic aggregates is believed to be indicative either of an early extrusive flow or of the chilled margin of an intrusive igneous pluton. The earliest recognizable mineral is 2M muscovite in large, shredded flakes. If this and the biotite and quartz are indicative of the early igneous chemical composition, the original lithology may have been of rhyolitic to intermediate composition, certainly of low CaO content. The high total rubidium content and low total strontium content (Table 3) also are suggestive of a silica-rich lithology (Vlasov, 1966, p. 51 and 136).

THE GRANITE

Granitic lithologies in the core are of varied textures and mineral abundance, and exhibit a complex geological history.

Mesocratic granite that is equigranular to subequigranular and largely holocrystalline, exhibiting only a weak foliation, occurs at the base of the core at 5972 feet (Figure 1-A). A sample from this lithology was used for radiometric dating. Above 5972 feet, granitic material is leucocratic to mesocratic, depending largely on the amount of biotite inclusions and replacement sericite. It ranges from fine grained (highly sericitic) to coarse grained (pegmatitic and quartz-rich) and ranges in form from boudinage-like pods (Figure 1-B) to banded (Figure 1-C) and irregularly segregated schlieren (Figures 1-D and 2-B). Above 5972 feet, the texture of granitic material is coarser grained and the form is wholly or largely controlled by the schistosity of the host biotite gneiss (Figures 1-B and 1-C).

The range in mineralogical composition of granitic materials is broad. However, excluding replacement sericite, the major minerals are quartz and microcline with minor albite-oligoclase and well-crystallized 2M muscovite (Table 2). Banded and pod-like forms differ somewhat in composition from the representative granite at 5972 feet (Table 2). Mineral content locally is more variable than Table 2 indicates, particu-

larly for quartz content: some laminae and transecting veins are almost wholly quartz with only traces of muscovite and feldspar. Well-crystallized muscovite is most prevalent in the coarse grained to pegmatitic areas (Table 2, 5964 feet and 5955 feet). Sericite is extremely variable in distribution, but always is present (Tables 1 and 2). Small, ragged flakes of biotite occur as inclusions from the quartz-biotite gneiss near the gneiss contact, decreasing in abundance away from the contact, and consequently are irregular in distribution (Table 2). In contradistinction to the unaltered biotite of the quartz-biotite gneiss, some of the biotite in the granite at 5972 feet is altered to, and interleaved with, chlorite, indicating a minor amount of retrograde metamorphism of biotite that did not affect the gneiss. The orthoclase noted at 5972 feet is untwinned potassic feldspar and may be, in part, microcline (especially since orthoclase was not detected on X-ray patterns). Plagioclase is in part kaolinized and severely sericitized. Some microcline also is sericitized. Zircons are ellipsoidal, rounded, detrital grains with very little elongation. In two upper-core

Table 2. *Mineral Compositions of Granitic Lithologies**

	HM2-GS Isotopically Dated Granite, 5972′	*Pegmatitic Banded Granite, 5964′*	*Sericitic Banded Granite, 5955′*	*Granite: Sericitic Pod, 5950′*	*Granite Average*
Quartz	35	42	47	26	63
2M Muscovite	~ 1	5	5	n.d.	5
1Md Muscovite	34	34	35	38	
Biotite	7	n.d.	10	n.d.	
Microcline	12	9	< 1	5	15
Orthoclase	< 2	n.d.	n.d.	n.d.	3
Plagioclase	3	n.d.	n.d.	2	3
Chlorite	2	} 6	n.d.	n.d.	} 5
Kaolinite	< 1		n.d.	n.d.	
Zircon	< 1	n.d.	n.d.	n.d.	< 1
Sphene	?	n.d.	n.d.	n.d.	
Tourmaline	?	n.d.	n.d.	n.d.	
Apatite	?	n.d.	n.d.	n.d.	
Pyrite	n.d.	n.d.	n.d.	~ 2	
Magnetite	~ 1	~ 1	n.d.	n.d.	2
"Clay"†	n.d.	n.d.	~ 3	26	~ 3
	99°	97	100	99	99°

* Determined petrographically at 5972′ and estimated by X-ray analysis at 5964′, 5955′, and 5950′.

† A broad X-ray reflection at about 11Å.

° Recalculated average granite composition, excluding biotite inclusions and sericitization.

n.d. = not detected.

samples, a broad interstratified or partially collapsed clay-mineral X-ray reflection occurs at about 11Å that is distinct from the also broad sericite reflection at 10Å (Table 2). At 5964 feet, a 7Å X-ray reflection is present without a 14Å reflection and hence may be kaolinite.

Petrographic examination of the granite at 5972 feet revealed additional data pertinent to the interpretation of geologic processes. Quartz, anhedral to subhedral and generally unstrained, is of at least two generations; rounded cores with rim quartz are common and also occur above 5972 feet in coarse-grained segregates. Thin veinlets composed wholly of quartz transect the granite at 5972 feet and the biotite gneiss at 5955 feet (Figure 2). Small aggregates of quartz and muscovite are rimmed or replaced by quartz and potassic feldspar. All minerals are embayed or replaced by sericite. Biotite, present mostly near the contact of the granite with quartz-biotite gneiss, preserves a weak but disoriented foliation.

The earliest recognized minerals in the granite are quartz and muscovite, both of which occur as inclusions in biotite derived from the adjacent quartz-biotite gneiss. This early muscovite is intermediate in grain size between sericite and late, large, crystal flakes, is more shredded than the later flakes, and occurs in quartz aggregates or in biotite where it has been protected from subsequent replacement. The next minor mineral to crystallize was microcline, with or without quartz and sodic plagioclase. It contains inclusions of quartz, muscovite, and biotite and clearly replaces or disrupts biotite flakes (also see Figure 2-A). The minor chloritization of biotite may have occurred during a late stage of granite crystallization; the sequence is not clear because the small amount of chlorite present is interleaved with biotite and is not present as a replacement rim. Some quartz appears to be replacing microcline (ragged embayments) and it may be related to late quartz-filled fractures. All of these minerals were then invaded and replaced by sericite without any regular spatial, and therefore genetic, relationship to plagioclase or potassic feldspar (see Figure 2-D).

The granite at 5972 feet and the compositionally similar bands and pods above are hybrid rocks, containing inclusions of biotite and biotite gneiss. The replaced aggregates of quartz and muscovite also may represent rafted inclusions, perhaps from a metasedimentary unit that contained the rounded zircons observed in the granite sample at 5972 feet. The quartz-rich lit-par-lit injections into biotite gneiss above granite at the 5972-foot level are interpreted as a late-stage mobilization at the granite phase. The process yielding sericitization is not clear. However, it was not merely an *in situ* process such as might result from burial metamorphism but clearly was one of mobilization, replacing both granite and gneiss and partially obliterating schistosity and gneissic banding.

CONTACT RELATIONSHIPS

The contact between quartz-biotite gneiss and granite at 5972 feet, first described by Saylor (1968), yields information pertinent to age relationships between the two lithologies. Saylor (1968, p. 7) noted that the contact on the granite side is coarser grained, more leucocratic and contains more quartz and muscovite than the granite into which it grades. He ascribed an origin for this coarser-grained phase to an influx of "pegmatitic fluids" along the gneiss and granite contact.

Coarse-grained granitic material clearly has penetrated schistose biotite gneiss (Figure 1-A) and disrupted the biotite foliation (Figures 1-A and 2-A). Its contacts in the biotite gneiss generally are sharp but, in the granite, textures tend to grade into pegmatitic sizes. There is no evidence of a fine-grained chilled contact either of the granite or of the pegmatite at their contacts with biotite gneiss. A few cross-cutting quartz veinlets cut both granite and gneiss. Biotite inclusions are most abundant in granite near its contact with gneiss. As a consequence of these observations, both the granite and its pegmatitic phase are demonstrably intrusive into, and hence somewhat younger than, the gneiss.

Quartz-rich pegmatitic granite has a simpler mineralogy than normal granite. It is composed of quartz (two generations as in the granite), large muscovite flakes, and minor potassic feldspar. Rocks of this type occur throughout the vertical core succession. Sericite commonly is absent; where present, it replaces only the fringes of tightly interlocked quartz aggregates. The sequence of mineralization is similar to that of the granite.

SUMMARY AND CONCLUSIONS

From the foregoing discussion, several general conclusions are warranted, all of which pertain to interpretations of the isotopic age dates.

The core contains several lithologies that can be interpreted as successive stages of crystalliation, recrystallization, and replacement, some of which involved deformation of the rock fabric. In the biotite gneiss, there are relicts believed to indicate a pre-existing igneous rock, possibly extrusive. This lithology, now a metamorphosed and foliated gneiss, persists upward in continuous core to a quartzite that is believed to be Cambrian and hence the gneiss represents the youngest major Precambrian lithology preserved at this locality. Relict minerals in a weakly foliated granite from the base of the core indicate the inclusion and assimilation of a (meta) sediment from below that contained muscovite and quartz with traces of rounded zircons.

Following the establishment of a foliated, banded gneiss by the metamorphism of a pre-existing lithology, injection of a microcline granite

disrupted the biotite gneiss, including and assimilating portions of it. A late stage in the process involved mobilization of a more quartz-rich and pegmatitic fraction that invaded the biotite gneiss, and yielded lit-par-lit injections above the microcline granite. Minor deformation, fracturing and slip folding, accompanied late-stage granite development. The final event involved the invasion of sericite into all lithologies below Cambrian (?) quartzite.

Alteration differs in the two major lithologies. Biotite in the gneiss has not been subjected to retrograde mineralization, whereas the sparse biotite inclusions in the granite are somewhat chloritized, suggesting that in granite chlorite resulted from a late hydrous phase alteration. Sericite transects the foliation of biotite gneiss but there is little evidence of actual replacement of quartz or biotite. In the granite on the other hand, microcline is heavily sericitized, much of the plagioclase is sericitized, and some of the quartz is embayed. Consequently, sericitization also may be a late stage continuation of the granitizing process. Additional alteration of plagioclase to kaolinite has been noted throughout the core in the granitic segregates.

ISOTOPIC DATING

RESULTS

One sample of biotite gneiss for K/Ar and Rb/Sr dating and one sample of the microcline granite for Rb/Sr dating were submitted to Isotopes Inc. (Teledyne) for analysis. The constants used and the isotopic concentrations are given in Table 3. Analytical error indicated was calculated using the RMS* summation method. All observed Sr^{86}/Sr^{88} ratios were normalized to a Sr^{86}/Sr^{88} of 0.1194, and the observed Sr^{87}/Sr^{86} ratios were adjusted by half that amount. The samples for Rb/Sr analysis were analyzed on a rhenium triple-filament ion source. A 12-inch, 60^0 mass spectrometer with electron multiplier detector was used. Apparent ages reported by the laboratory assuming an initial Sr^{87}/Sr^{86} ratio of 0.7050 and $\lambda = 1.47 \times 10^{-11} yr^{-1}$ for Rb^{87} are:

HM2-BP (biotite gneiss): 546 m.y. ± 15
HM2-GS (microcline granite): 631 m.y. ± 19

All analyses were performed as whole-rock samples.

The K/Ar age of 908 ± 9 m.y. obtained on biotite gneiss (Table 3), largely from biotite (75%) and sericite (25%), clearly indicates a Precambrian age for the original lithology and for its metamorphism to gneiss; that is, the apparent age is compatible with age ranges for Grenville metamorphic rocks (Tilton and others, 1960; Bass, 1960; Rudman

* root mean square

Table 3. *Isotopic Data and Apparent Ages of Gneiss and Granite*

A. K/Ar System

Sample No.	*Rock Type*	*scc Ar^{rad}/gm*	*$Ar^{rad}Ar^{tot.}$*	*% K*	*Apparent Age (m.y.)*
HM2-BP	Whole Rock, Biotite Schist	1.662×10^{-4}	0.98	3.58	908.4 ± 9

$\lambda\beta = 4.72 \times 10^{-10} yr.^{-1}$, $\lambda\gamma = 5.85 \times 10^{-11} yr.^{-1}$, $K^{40} = 1.19 \times 10^{-4}$ atom percent of natural K

B. Rb/Sr System

Sample No.	*Rock Type*	*Rb(ppm)*	*Sr(ppm)*	*Rb^{87}/Sr^{86}*	*(Sr^{87}/Sr^{86})**	*Apparent Age (m.y.)*	
						λ 1.47	λ 1.39
HM2-BP	Whole Rock, Biotite Schist	227.3	33.7	19.05	0.8584	530	560
HM2-GS	Whole Rock, Granite	111.2	89.8	3.50	0.7376	530	565

$\lambda\, Rb^{87} = 1.47 \times 10^{-11} yr.^{-1}$ or $1.39 \times 10^{-11} yr.^{-1}$

$$\left\{ \begin{array}{l} Rb^{85} = 72.15\% \\ Rb^{87} = 27.85\% \end{array} \right\}$$

* Sr^{87}/Sr^{86} ratios normalized to $Sr^{86}/Sr^{88} = 0.1194$

initial ratio $(Sr^{87}/Sr^{86})_0 = 0.710$

Standardization: $Sr^{87}/Sr^{86} = 0.7077 \pm .0003$ for Eimer and Amend $SrCO_3$, Lot 492327

and others, 1965; Lidiak and others, 1966; Goldich and others, 1966; Muehlberger and others, 1967). Assuming no gain or loss of argon from the whole-rock system and assuming that 1100 million years is a maximum age for biotite metamorphic crystallization, then a minimal age of about 330 million years is obtained for the sericite to yield a mixed-mineral and whole-rock age of about 910 million years. If the maximum apparent age of the biotite were 1000 million years or less at the time of sericitization, then the minimal age of the sericitization for a mixed whole-rock age is upper Precambrian rather than lower to middle Paleozoic. Lack of closure after sericitization would similarly require an age for the sericitization considerably older than 330 million years. Some lack of closure for biotite (i.e., a younger apparent age) seems reasonable based on some expectable argon loss resulting from granite injection, sericitization, and perhaps from burial under at least 11,000 feet of Precambrian and Paleozoic sediments in the plateau; however, argon loss to the whole-rock biotite gneiss system can be expected to have been somewhat less. Because sericitization apparently did not affect the overlying Cambrian quartzite and dolomite and because considerable erosion must have occurred before dolomite deposition, the age of the sericitization is probably greater than 600 million years.

The Rb/Sr ages reported by Isotopes, Inc., using $\lambda = 1.47 \times 10^{-11}yr^{-1}$ and $(Sr^{87}/Sr^{86})_0$, are discordant (using a λ of $1.39 \times 10^{-11}yr^{-1}$ will increase the calculated age by about 6%). Plotting the two sample analyses on an isochron diagram (Figure 4) yields a concordant apparent Cambrian age for the gneiss and the granite with an initial Sr^{87}/Sr^{86} of 0.710 (i.e., the intercept). The maximum possible calculated age is 750 million years for the granite using $\lambda = 1.39 \times 10^{-11}yr^{-1}$ and $(Sr^{87}/Sr^{86})_0 = 0.700$ (Figure 4). Thus, it is not possible to calculate apparent Rb/Sr dates that will be concordant with the gneiss K/Ar date.

Several observations regarding this discordancy are of particular interest. 1) The same sample of biotite gneiss was used for K/Ar and Rb/Sr isotopic analysis, yet the age discordancy between the two methods is large, regardless of whether a Rb/Sr isochron is valid. 2) The calculated Rb/Sr ages are considerably younger than those obtained by the K/Ar method. In most isotopic analyses where both methods have been used, the Rb/Sr age is older or essentially concordant, particularly where biotite was the major contributor to the whole-rock age (Tilton and others, 1960; Kulp in Kulp and Eckleman, 1961, p. 417; Hart, 1964; Lanphere and others, 1964, p. 295-296, 306; Lidiak and others, 1966; Lyons and Faul, 1969, p. 307; Hanson, 1971). Exceptions have been noted however (Tilton and others, 1960, Table 5; Lanphere and others, 1964, p. 302). Furthermore, Goldich and others (1966) concluded that "the Rb/Sr sytem of bio-

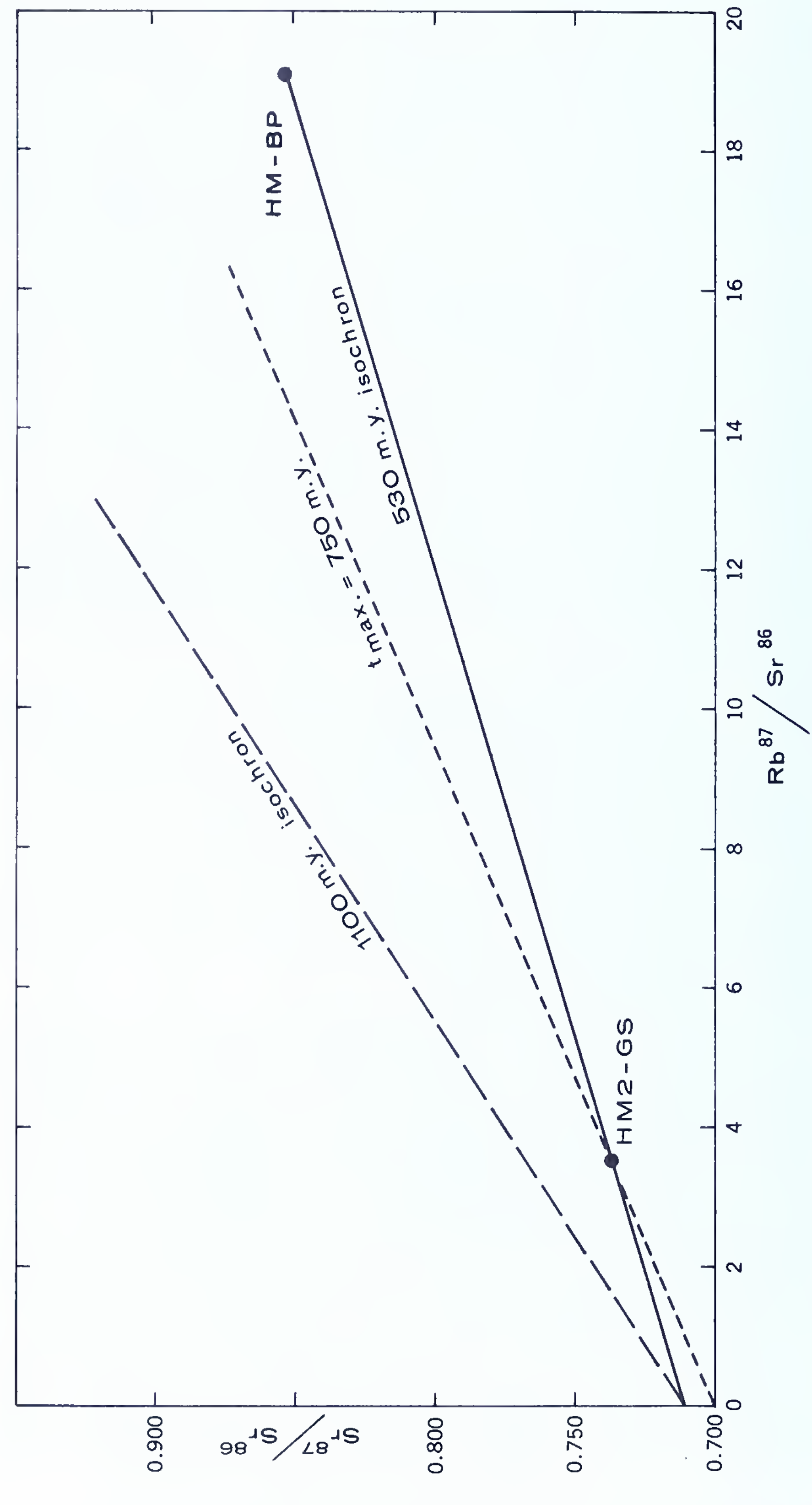

Figure 4. Isochron plot of Sr^{87}/Sr^{86} vs. Rb^{87}/Sr^{86} for biotite gneiss (HM2-BP) and microcline granite (HM2-GS) at 5972 feet illustrating apparent concordance at about 530 million years for $(Sr^{87}/Sr^{86})_0 = 0.710$ and $\lambda Rb^{87} = 1.47 \times 10^{-11}\ yr^{-1}$.

tite is the more sensitive to mineral alteration" (p. 5380) and that the older K/Ar dates are more likely if the biotite is coarse grained (p. 5380). This, however, is less applicable to whole-rock analyses. The only samples reported with a comparable age discrepancy are for biotite in the gneiss at Devault, Pennsylvania, for which Rb/Sr and K/Ar dates are 630 million years and 900 million years respectively (sample A) and 485 million years and 1010 million years respectively (sample B) reported by Tilton and others (1960). 3) The validity of the Rb/Sr isochron must be evaluated and the discordancy with the K/Ar analysis must be considered in the light of the observed multiplicity of geologic processes that have acted on the total gneiss-granite system.

DISCUSSION OF AGE DISCORDANCY

The discrepancy in apparent age between the K/Ar and Rb/Sr methods on the same biotite gneiss sample is nearly 400 million years (Table 3). If the K/Ar system were assumed to be the cause of the discrepancy, argon would have to have been inherited. This does not seem plausible. The biotite of the gneiss is a pervasive metamorphic crystallization and the earliest recorded alteration. Equilibration in the K/Ar system would have been complete at the time of metamorphism. Furthermore, the age obtained by K/Ar analysis is a typical Grenville metamorphic age. For example, Lidiak and others (1966) report a mean K/Ar age of 937 million years for 10 samples of Grenville basement, the difference between 937 million years and 1000 million years (approximately the presumed time of metamorphism) being attributed to thermal loss caused by burial metamorphism or by subsequent orogenies. As appears to be the case for the Erie County gneiss, subsequent argon loss generally has been rather small. It should also be pointed out that other basement samples reported in the literature have not shown any of the extensive sericitization noted here, yet their apparent K/Ar ages are comparable. Consequently, the sericitization in the Erie County gneiss appears to have had little if any additional effect on the whole rock K/Ar age. This line of reasoning would indicate that the age of the sericitization could be 900 million years or more, although a "mixed" age (e.g., 1000 million years for non-re-equilibrated biotite with 530-560 million year sericite) is possible. On the other hand, on the grounds that both granitic injection and sericitization would be likely to have re-equilibrated the biotite in the gneiss K/Ar system, a mixed age would not be expectable and again a minimal age of about 900 million years for the sericitization (and the granite injection) seems most reasonable. A final possibility is that the resultant whole-rock age of 908 million years results from a combination of partial re-equilibration of

biotite and a mixed biotite-sericite age, in which case the sericitization is older than about 500 million years by some unknown amount.

Because the apparent-age discrepancy is not attributable in any significant measure to the K/Ar system in the biotite gneiss, an explanation must be sought in the Rb/Sr system of both gneiss and granite. Two types of problems are involved: the validity of using an isochron at about 530-560 million years from these data (Figure 4) and the possible geologic events relatable to distributions in the Rb/Sr isotopic system.

Although the variation of Sr^{87}/Sr^{86} with Rb^{87}/Sr^{86} between multiple samples (an isochron diagram) yields a more reliable "original" rock age for whole-rock samples than for mineral separates, several assumptions are involved; chiefly, that the rock system was closed and that the rocks had the same initial strontium composition. For the suite studied here, an isochron line can be drawn through the two whole-rock points (Figure 4) but the determination of scatter from this line, and hence the closure of the system, requires more than two points (e.g., Lanphere and others, 1964, p. 283). The only available "evidence" for a closed system (other than the lack of visible biotite alteration in the gneiss) is rather circular: the two points define a line which does yield a reasonable initial Sr^{87}/Sr^{86} ratio (cf. Table 4). In addition, the wide Rb^{87}/Sr^{86} range for the two dated samples is sufficient to yield a moderately reliable isochron. Because no assumed values for initial Sr^{87}/Sr^{86} for either rock type will yield even the minimal age (908 million years) and because the biotite-grade metamorphism is pervasive, it seems reasonable to accept the assumption of uniform "initial" strontium with a compositional ratio of 0.710 or slightly less for gneiss in the age range of 400 to 1000 million years (Table 4). Finally, the apparent agreement at 530-560 million years obtained from two such different lithologies, that is from biotite gneiss and granite, does not permit a large scatter from a whole-rock isochron unless neither lithology (particularly the biotite gneiss isotopic composition) lies near a single isochron. Thus, in lieu of evidence to the contrary, it can be assumed that the strontium composition in both units at the time(s) of Rb-Sr isotopic redistribution was uniform for both lithologies and that an approximate isochron that does not represent an original rock age has reasonable validity. Consequently, several cases will be evaluated as possible explanations for this apparent isochron.

Among the observed events, explanation of a 530-560 million year age for granite injection seems unlikely. As noted, the injection of granitic material is pervasive and represents a temperature of crystallization sufficiently high to have re-equilibrated K/Ar ratios in the biotite gneiss. Even less likely, also noted previously, is a mixed-mineral age resulting from sericitization younger than 530 million years; that is, an unre-equilibrated

mineral mixture of middle or late Paleozoic sericite with 1000 million year (or older) biotite in the gneiss and with 908 million year (or older) potassic feldspar in the granite. In addition to the likelihood of re-equilibration, these minerals do not occur in the proper ratios (Table 1 and 2) to yield a single 530-560 million year mixed age for both units. Furthermore, the feldspars in the granite are notably altered by the sericitization such that the isotopic composition of the granite would have been affected, yielding some degree of Rb-Sr homogenization. (In the biotite gneiss there is no visible evidence that biotite flakes have been affected by sericitization, although the fabric is transected.)

Table 4. *Selected Initial Sr^{87}/Sr^{86} Ratios for Crustal and Mantle-Derived Rocks*

$(Sr^{87}/Sr^{86})_0$	*Age (m.y.)*	*Rock Unit*	*References*
$<$ 0.702	1200	Gneisses	Hedge and Walthall, 1963
0.7023-.7050	519-595	Lower-crustal granite	Fullagar, 1970
0.702-0.711	250-2500	Granites	Hedge and Walthall, 1963
0.702-0.711		Continental basalts	Hamilton, 1965, p. 108
0.704-0.706	1000	Basement lithologies	Goldich and others, 1966
0.705	420	Monzonite	Wetherill and others, 1966
0.705	u-Pc	Granite	Fairbairn and others, 1965
~ 0.705	1000	Mantle-derived rocks	Lyons and Faul, 1969
0.705-0.707	1100	Anatectic gneiss	Bickford and Turner, 1971
0.707	u-Pc	Gneiss	Fairbairn and others, 1965
0.707	l. Dev.	Volcanic rocks	Bottino and Fullagar, 1966
0.708	64-156	Gneiss and phlogopite	Lanphere and others, 1964, p. 302
0.709-0.710	Silurian	Porphyritic and volcanic biotite	Boffinger and others, 1970

A choice is more difficult among the remaining possibilities: 1) sericitization at 530-560 million years with re-equilibration and homogenization, 2) radiogenic Sr^{87} loss, or Rb addition, at 530-560 million years with sericitization at an earlier time (e.g., at 908 million years), and 3) radiogenic Sr^{87} loss, or Rb addition, younger than 530-560 million years with an older sericitization (e.g. at 908 million years), in which case interpretation of the isotopic data as an isochron would not be a valid representation. This last case requires partial re-equilibration from an older event such that an "average" age of 530-560 million years is obtained; for example, sericitization with equilibration at 908 million years and partial radiogenic Sr^{87} loss subsequent to 530-560 million years. As does the second possibility, this explanation requires an equivalent loss of radiogenic strontium from two very different lithologies—essentially from biotite and sericite in one and from potassic feldspar, sericite, and muscovite in the other. Also required for all three is that any process responsible for loss of strontium (or gain of rubidium) in both units could not have appreciably affected the argon concentrations in biotite gneiss.

If sericitization at 530 million years (supposition 1 above) caused Rb-Sr redistribution (loss of radiogenic Sr^{87} or gain of Rb), it did so at some considerable time after granite injection; that is, granite injection must be 908 million years old, or more. The close spatial association of granite and sericite could very well imply that both are genetically related and hence that such a time separation is unlikely. Alternatively, it could be argued that apparently both the sericitization and the 530-560 million year age are unique to this Precambrian core in comparison with otherwise similar cores dated from the basement of eastern Ohio (Bass, 1960; Lidiak and others, 1966; Muehlberger and others, 1967). Thus, an implication could be drawn that this unique age is a reflection of a locally unique sericitization. This argument is only as strong as the unsupported analogy; consequently, more weight is placed upon 1) the petrographically-based implication of a sericitization process closely allied in time to that of granite formation and 2) the stratigraphic implication that sericitization is older than the overlying Cambrian quartzite and dolomite.

As a consequence of the foregoing discussions it is proposed 1) that the pervasive sericitization (the youngest event observed in the rocks) occurred during Precambrian time, probably at or near 908 million years ago as a late-stage function of granite injection, 2) that radiogenic strontium has been lost from both the biotite gneiss and the microcline granite by a process that is not observable, that did not appreciably affect the K/Ar system of biotite, and that became a closed system about 530-560 million years ago, 3) that granite injection occurred about 1000 million years ago completely resetting both the K/Ar and Rb/Sr clocks (somewhat later slightly modified by sericitization and with Rb/Sr redistribution to 908 million years), and 4) that metamorphism of a pre-existing (volcanic ?) rock to biotite gneiss may have concluded about 1100 million years ago in accordance with other dated Grenville basement metamorphic events (Lidiak and others, 1966).

If these proposed correlations are correct, there has been considerable independence in the reaction of both units to processes controlling the two isotopic dating systems: argon largely has been retained in biotite gneiss while radiogenic strontium has been lost from it, and also from sericite and potassic feldspar in granite. Discussions in the literature are not unanimous on the probability of, or processes involved in, such an explanation. One of the best documented examples is the World Beater Complex where radiogenic strontium has been lost from the total rock system and from biotite, both during and after metamorphism, with some of the radiogenic strontium becoming enriched in hornblende diorite several miles distant (Lanphere and others, 1964). Fairbairn and others (1967) in a study of the Hoppin Hill granite noted an apparent isochron

of reduced slope (younger apparent age) resulting from an increase in Rb/Sr in the total rock system which they suggest may be causally related to an assumed major unconformity (Lanphere and others, p. 323). Both Lanphere and others (1964, p. 303) and Goldich and others (1966, p. 5377) note that there can be Rb/Sr re-equilibration without supporting petrographic evidence. As noted by Lanphere and others (1964, p. 304) less radiogenic strontium would have to be removed from biotite than rubidium added to it and consequently strontium migration may be the more likely process. Entrapment of rubidium by micas and clays (Vlasov, 1966, p. 143-144, 152) with leaching out of Sr^{87} and total strontium by ground water base exchange (Kulp in Kulp and Eckleman, 1961, p. 4, 17; Kulp and Bassett, 1961) or in an acid environment (Chaudhuri and others, 1970) have been proposed to explain anomalously low dates or samples whose isotopic ratios scatter below an established isochron. Deep burial also has been suggested as a cause of Sr^{87} leakage from micas (Riley, 1970, p. 718) although burial also would be expected to affect the K/Ar age by argon leakage.

Opposite points of view also have been expressed and could apply to the Erie core samples. For example, leaching or base exchange in two different lithologies might not be expected to yield an approximate isochron, but a scatter of points instead (e.g., the World Beater Complex, Lanphere and others 1964, p. 306-309). The data given here do not support or deny such a scatter. At temperatures of 300°C, as summarized by Hanson (1971, p. 101), argon is lost somewhat more readily than strontium from biotite. Brooks (1966) noted that biotite lost little to no radiogenic strontium (up to 4%) in the Heemskirk granite; instead, strontium was lost primarily from potassic feldspar and gained by plagioclase so that biotite and whole-rock ages tended to be quite similar.

In summary, it does seem permissible to ascribe the apparent Rb/Sr isochron to a low-temperature event that caused preferential leaching of radiogenic strontium from both granite and biotite gneiss without appreciably affecting the K/Ar ratio of biotite in the same gneiss. Consequently, it is believed that whole-rock Rb/Sr analysis does not yield an original rock age, an age of homogenization during metamorphism, nor an age of granite injection into the metamorphic gneiss. On the other hand, this interpretation is not wholly satisfactory; that is, it does not explain why argon also has not been lost from the same biotite gneiss from which radiogenic strontium has been lost nor does it explain how a strontium-leaching process will remove approximately the same amount from a biotite-sericite gneiss as from a microcline-sericite-muscovite granite. Undoubtedly some of these problems could be clarified if more basement samples from this area were isotopically analyzed.

CONCLUSIONS

A more complex geologic history than heretofore recognized in the basement rocks of northwestern Pennsylvania has been described from core samples near Erie, Pennsylvania. A rock originally of silicic to intermediate composition with apparent relict phenocrysts was metamorphosed to a biotite gneiss, in places schistose, with a pervasive foliation. This metamorphism is believed to correlate with regional metamorphism of the Grenville province and with basement metamorphism in eastern Ohio at 1000 or 1100 million years. Subsequently, perhaps at about 1000 million years, a microcline granite intruded the gneiss, disrupted its foliation, and was injected upward as a lit-par-lit striped gneiss with granitic segregates similar to schlieren with only a weakly superimposed foliation. Final stages of crystallization included fracturing of both granite and gneiss with minor crystallization of pegmatite quartz, muscovite, and microcline. Early quartz and muscovite with rounded zircons in the granite may indicate inclusions from a lithology lower in the section and/or a migmatic origin for the granitic fluids. These events are believed to be represented by a K/Ar minimum age of 908 million years on the biotite gneiss. Fine-grained (sericitic) muscovite transects the fabric of the gneiss, with no visible petrographic evidence of replacement of the biotite, and also transects the weaker fabric of the granite, replacing earlier muscovite, plagioclase, microcline, and embaying quartz.

The biotite gneiss sample, dated at 908 million years by the K/Ar method, and a sample of the microcline granite in contact with the gneiss, both from a depth of 5972 feet yield apparently concordant Rb/Sr whole-rock ages at about 530-560 million years with a Sr^{87}/Sr^{86} intercept of 0.710. These apparent ages represent an extreme case of discordancy between the K/Ar and Rb/Sr methods for a Precambrian basement sample. The only comparable age discordancy is for biotite from Baltimore Gneiss near Devault in eastern Pennsylvania for which K/Ar ages of 900 million years and 1010 million years and Rb/Sr ages of 630 million years (Table 5) and 485 million years were obtained (Tilton and others, 1960). However, whole-rock ages were not obtained on the Baltimore Gneiss samples; hence, their age discrepancy may be considerably less than reported. In addition, the Baltimore Gneiss samples were obtained from outcrop where low-temperature leaching might be expected to have played a significant role in redistribution of strontium isotopic composition.

Although it is possible that the 530 to 560 million year ages represent the time of sericitization of both lithologies, it is believed more likely that sericitization was considerably older, approaching the 908 million year K/Ar age determination. Petrographic data indicate that sericitization is rather closely associated with the granite, the granitic pegmatite, and their

Table 5. *Selected Isotopic Age Dates and Orogenic Terminology between 500 m.y. and 650 m.y. in the Appalachians*

Apparent age (m.y.)	*Lithology*	*Isotopic System*	*Reference*
500-640	Coldbrook volcanic equivalents	K/Ar	Lowdon and others, 1963; Leech and others, 1963
540-640	Granites, Mass.	Rb/Sr; W.R.	Fairbairn and others, 1967
600, 640	Basement Grenville granite	Rb/Sr; K/Ar	Lidiak and others, 1966
630	Devault gneiss (A), Pa.	Rb/Sr; Biotite	Tilton and others, 1960
519-595	Granites, SE Appalachians	Rb/Sr; W.R.	Fullagar, 1970
580	Baltimore Gabbro, Md.	K/Ar; Plag.	Wetherill and others, 1966
580	Holyrood Granite, Newf.	Rb/Sr; W.R.	Fairbairn, 1958; McCartney and others, 1966
575	Yonkers gneiss, N.Y.	Rb/Sr; W.R.	Long, 1969
565	Holyrood Granite, Newf.	Rb/Sr; Feldspar	Fairbairn, 1958; McCartney and others, 1966
565	Norbeck pluton, Md.	U/Pb; Zircon	Wetherill and others, 1966
550	Conshohocken gneiss, Pa.	K/Ar; Biotite	Tilton and others, 1960
> 530	Wissahickon Schist, Pa.	Pb-α; Monazite	Jaffe and others, 1959
510-540	Kensington pluton, Md.	U/Pb; Zircon	Wetherill and others, 1966
518	Nova Scotia granite		Fairbairn and others, 1960
468-537	NE Appalachian volcanism	Rb/Sr; W.R.	Fairbairn and others, 1966
> 460	Gabbro, Pa.	K/Ar; W.R.	Lapham and Bassett, 1964

Terminology

Late Precambrian	Avalonian	Lilly, 1966
460-600 m.y.	proto-Taconic (post Precambrian)	Lapham and Root, 1971
570±20	Neponset (in Massachusetts)	Fairbairn and others, 1967
pre-middle Ordovician	Penobscot (includes late Cambrian?)	Neuman, 1967

Plag. = Plagioclase
W.R. = Whole Rock

injections into biotite gneiss. Consequently, there may not have been a large time separation between the two events and an age of 900-1000 million years for the granite would also approximate that for sericitization. Secondly, the sericitization would be expected to have affected the K/Ar age of the biotite gneiss; yet, the gneiss is approximately the same age as, or only slightly younger than, other reported ages from the Grenville basement and where no sericitization has been reported. Consequently, the sericitization of the gneiss either did not affect the K/Ar system or its age closely approaches the 908 million year determination. In addition, using the observed percentages of biotite and sericite in the gneiss a mixed age of 530 to 560 million years for sericite and 1000 million years for biotite is unlikely, although a mixed age of 530 to 560 million year sericite and 1100 million year biotite is possible. However, a mixed age for which there has been no re-equilibration in the K/Ar system seems highly unlikely. Finally, sericitization appears to have preceded erosion and subsequent Cambrian sediment deposition.

From examination of the possible interpretations of Rb/Sr age determinations, it seems most reasonable to conclude that they represent closure of the Rb/Sr system, a system in which radiogenic Sr^{87} migrated out of the whole-rock system of both the gneiss and the granite. Thus, the whole-rock Rb/Sr apparent age is not in any sense an original age and it is not the isotopic representation of any petrographically observable event. This interpretation requires radiogenic strontium leaching from two quite different lithologies such that isotopic ratios lie along an apparent isochron. Because point scatter cannot be accurately determined from two points and because such a leaching process cannot be documented, this interpretation of a 530 to 560 million year strontium migration is not completely satisfactory and must be viewed with some skepticism.

The postulated Cambrian "event" in the Erie County Precambrian basement is the youngest recorded lower Paleozoic age from buried basement samples. It also is the westernmost example of possibly correlative but better defined events that occurred between 500 million years and 650 million years ago in the Appalachians for which an increasing amount of age data are becoming available from outcrop samples (Table 5). Terminology for these events on more than a local scale has not been established and time limits are not clearly defined (Table 5), but it is clear that plutonic intrusion, volcanism, metamorphism, and alteration of Precambrian lithologies occurred during this span, apparently at different times and perhaps not correlatable from one locality to another. It is therefore not wholly unreasonable to suggest a low-temperature event during this time in the Precambrian of northwestern Pennsylvania even though this site is considerably west of the main loci of early deformation of the Appalachian geosyncline.

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